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(54) Bonding integrated circuit devices

(57) In the manufacture of a flip chip bonded hybrid integrated circuit device having a substrate 1 and a flip chip 3 joined by solder bonds 7, 8, the bonds occupying portions of the substrate surface which have dissimilar bond areas, the bonds 8 which occupy the smaller ones of the bond areas on the substrate have a solder volume arranged such that the resulting minor bonds after their formation adopt a joint shape with generally concave side walls. The provision of the concave side walls acts to increase the fatigue life of the joint so that device reliability is improved.

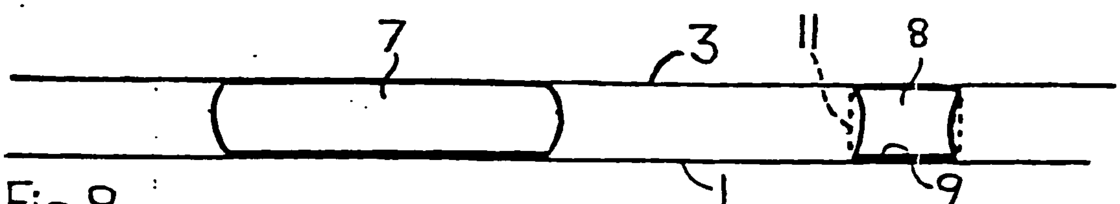

Fig. 9

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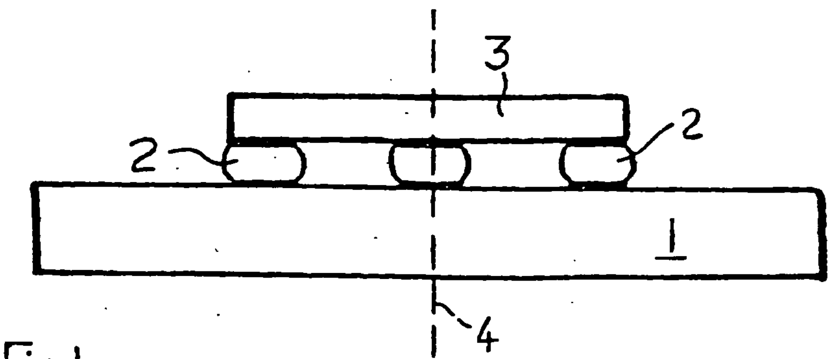

Fig.1

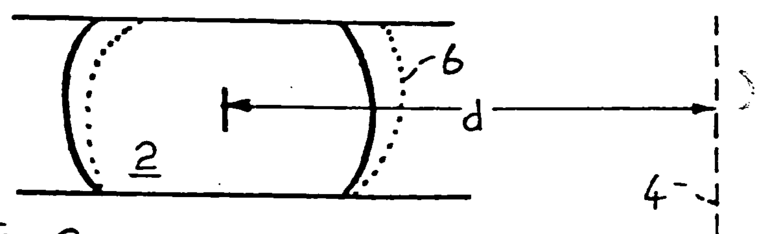

Fig.2

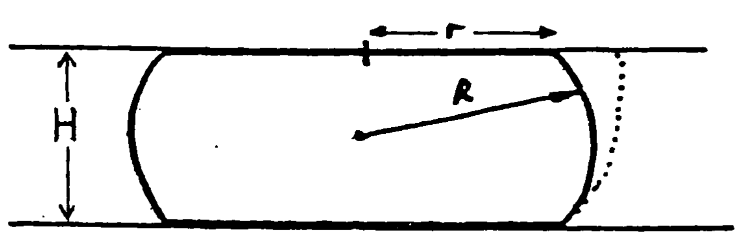

Fig.3

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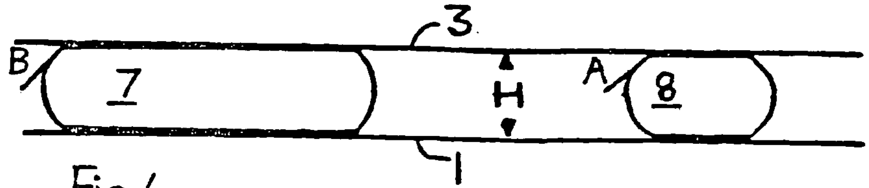

Fig.4

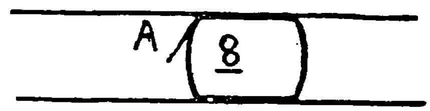

Fig.5

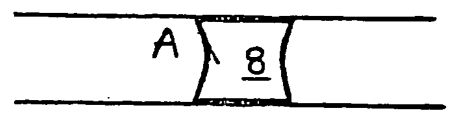

Fig.6

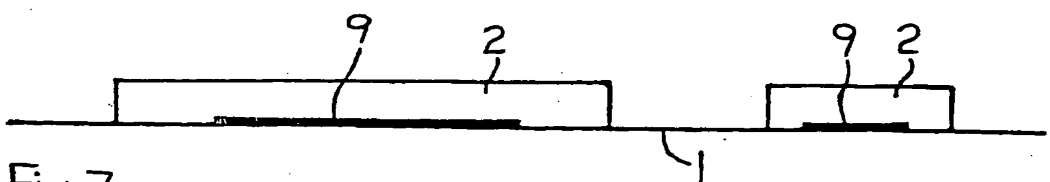

Fig.7

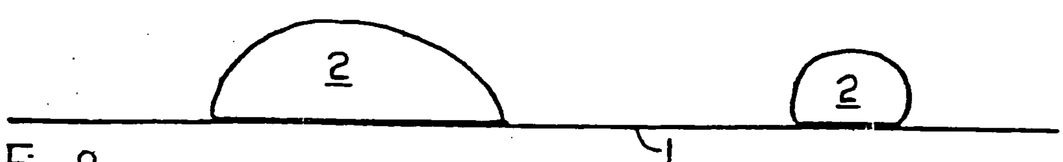

Fig.8

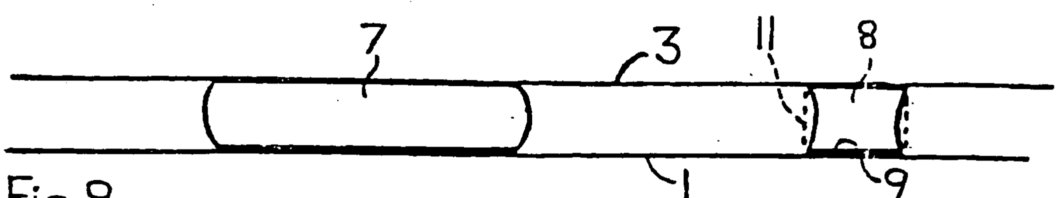

Fig.9

SPECIFICATION

Integrated circuit devices

This invention relates to integrated circuit devices. It relates partiularly to devices of the flip chip solder bonded kind and discloses a method by which the reliability of the device in service may be improved.

One cause of failure in service of a flip chip solder bonded hybrid device can be due to a solder joint deformation effect where conditions of ambient temperature or power cycling have been experienced. A change of temperature can give rise to joint deformation as a result of a mismatch in the thermal expansion coefficients of the hybrid components. Equally a temperature gradient that may occur between expansion matched components in a flip chip bonded hybrid device can also result in a solder joint deformation. This joint deformation, under service conditions can actually determine and control the hybrid device life by reason of the potential fatigue failure of the solder joint.

It should be noted that the solder compositions commonly employed in flip chip bonded devices (for example, 95 weight percent of lead, five percent tin; melting range 310-314°C, are, at room temperature, operating at about one twentieth of the melting temperature on the Absolute Scale. At such temperatures, metal alloy yield strengths are low and any mechanical displacement between the separate components of a flip chip bonded hybrid device can be accommodated by an essentially plastic deformation of the solder joint material. The fatigue life of a solder joint under these conditions is determined by a mechanism termed its low cycle (thermal) fatigue. The actual fatigue life of a given solder joint is a relatively complex function of the level of joint deformation (which in turn is a function of expansion coefficients, temperature gradients and joint position relative to a neutral axis of the hybrid device), joint shape, solder joint ductility and cycle frequency and profile details. Thus, for example, the solder joint fatigue life has been described by a mathematical equation which takes into account the effects of creep and related time-temperature dependent properties of the solder material. The maximum strain in the joint, which determines the fatigue life, is a function of joint geometry and shape.

The present invention was devised to provide an improved construction of integrated circuit device which could allow an extension in the potential life in service expectancy of the device.

According to the invention, there is provided a flip chip bonded hybrid integrated circuit device having a substrate and a flip chip joined by solder bonds, the bond occupying portions of the [illegible] surface which have dissimilar bond areas, in which the bonds occupying the smaller ones of the band areas on the substrate have a solder volume arranged such that the resulting minor bonds after their formation adopt a joint shape with generally concave side walls.

Preferably, the said volume of the minor solder bonds is less than that of a right cylinder of radius equal to that of the smaller bond area with a height equal to that required for the intended spacing between said substrate and the flip chip.

The invention also comprises a method of making a flip chip bonded hybrid integrated circuit device comprising the steps of preparing a substrate body having major and minor bond areas to which a flip chip is to be joined, placing solder deposits about the said areas for eventually forming solder joints with the said chip, the quantities of solder for deposit on the said minor bond areas being proportioned to ensure that the eventual bonds formed about these minor areas will have generally concave side walls.

By way of example, some particular embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows schematically on a greatly enlarged scale the effects of solder joint displacement on thermal cycling in a flip chip solder bonded hybrid integrated circuit device;

Figures 2 and 3 show some of the dimensions that are significant in calculating the stresses involved;

Figures 4 to 6 show different possible bond geometries for flip chip bonded hybrid devices, and,

Figures 7 to 9 show the conditions required for depositing predetermined solder volumes for device joints.

As depicted in Figure 1, a flip chip hybrid device has a substrate 1 with several solder bonds 2 providing electrical connections and a physical support means for a flip chip device 3. The flip chip device 3 is required to be supported in a parallel arrangement with the substrate 1 so the solder masses 2 are located roughly equally on either side of a neutral axis 4 to ensure that the chip device 3 will not tend to tilt out of parallel during the operation of fusing the material of the solder masses 2.

After manufacture of the hybrid device, it can be expected to be put into service in an environment where it will be exposed to time and temperature changes on the material of the solder masses 2 and the effects of creep will also occur. Figure 2 shows some of these effects on a single solder mass 2 which is spaced by a distance *d* from the neutral axis 4. In this Figure, the upper surface of the solder material forming the mass 2 has been moved a short distance in the direction of the axis 4 and the volume of the solder mass has

therefore taken up the shape indicated by the dotted line 6.

Figure 3 shows the general geometry of the solder joint with an indication of the dimensions that might be needed for calculating the stresses involved.

Figure 4 shows the different bond geometries that occur when a flip chip bonded hybrid includes two, or more, different bond sizes. The bonds having the largest and the smallest areas are termed the major and minor bonds respectively. The present considerations apply particularly to the case where the total perimeter of all the major bonds significantly exceeds that of all the minor bonds and thus the overall equilibrium bond height, which is determined by the balance of surface tension forces between the total number of bonds, is dominated by the design of the major bonds. A number of different minor bond geometries may then be considered for a given, and to a first approximation, fixed major bond geometry.

The situation shown in Figure 4 has the major solder joint 7 volume and the minor solder joint 8 volume arranged so that both joints are the equilibrium joint shape for the required common joint height, H. The equilibrium shapes correspond to that of a simple truncated sphere.

The minor joint 8 under these circumstances will show a shorter thermal cycle fatigue life than will the major joint 7 for two reasons. Firstly, the fatigue life is controlled by the value of the maximum strain on a joint, and the maximum strain location occurs at a strain concentration region where the solder joint meets one of the hybrid surfaces, the maximum strain increasing as the angle *A* becomes more acute. The corresponding value for where the major solder joint 7 meets the hybrid surface is the angle *B*. Since *A* is less than *B* the minor bond experiences a higher strain than the major bond, with the result that fatigue crack nucleation will occur first at the minor bond.

Secondly, the fatigue life also depends upon the diameter of the relevant solder joint since this dimension is the distance over which a fatigue crack must propagate to cause a joint failure. The combination of higher local strain and the risk of a smaller crack site causing failure leads to the minor bond condition controlling fatigue life. Thus a reduction of the minor bond joint curvature, as depicted in Figure 5, can be used to reduce strain concentration and increase hybrid device reliability. The optimum joint geometry is illustrated in Figure 6, in which the minor joint is rendered concave rather than convex In shape. The point of maximum strain in the minor bond is now at the bond centre point and it is very considerably smaller than for the convex bond case. A limit on the concavity of the minor the minor solder bump height after initial bump formation must clearly be greater than the equilibrium bond height determined by the major bonds. Again the volume of the minor solder bond must be less than that of the right cylinder of radius equal to that of the minor bond with height equal to that of the major bond heights, in order for the minor bond to adopt a concave joint shape.

The conditions for depositing the required predetermined volumes of solder are depicted in Figures 7 to 9. Figure 7 shows the solder masses 2 as deposited on top of electrically conductive film areas 9 supported on the substrate 1. Subsequent fusion of the solder material causes this to form a globule which is centred on each conductive film area 9 on the substrate. The globule will be pulled into a shape having a minimum surface area by surface tension forces and clearly the height of the globule upon any particular conductive area will depend upon the volume of solder deposited on that area. As already mentioned, the globule height should be no less than the required joint height.

Figure 9 shows the profiles of the solder masses when the flip chip has been located in place on the substrate. The minor solder joint 8 has formed a concave shape which is somewhat smaller in volume than that of a cylinder based on the relevant electrically conductive film area 9. The profile of such a cylinder is indicated by the dotted line 11. The globule volume which forms a precursor for this bond should therefore be smaller than the volume of this cylinder in order to obtain the required concave side walls.

The foregoing description of an embodiment of the invention has been given by way of example only and a number of modifications may be made without departing from the scope of the invention as defined in the appended claims. For instance, it is not essential that the provision of bonds with generally concave side walls should be restricted only to the minor bond areas. In a different embodiment, the provision of bonds with concave side walls could be used for all of the bond areas on the substrate provided that some alternative means was adopted for maintaining the correct spacing between the two surfaces which is one of the normal functions of the major bond areas. 1. A flip chip bonded hybrid integrated circuit device having a substrate and a flip chip joined by solder bonds, the bonds occupying portions of the substrate surface which have dissimilar bond areas, in which the bonds occupying the smaller ones of the bond areas on the substrate have a solder volume arranged such that the resulting minor bonds after their formation adopt a joint shape with generally concave side walls.

2. A device as claimed in Claim 1, in which

less than that of a right cylinder of radius equal to that of the smaller bond area with a height equal to that required for the intended spacing between said substrate and flip chip.

3. A flip chip bonded hybrid integrated circuit device substantially as hereinbefore described with reference to the accompanying drawings.

4. A method of making a flip chip bonded hybrid integrated circuit device comprising the steps of preparing a substrate body having major and minor bond areas to which a flip chip is to be joined, placing solder deposits about the said areas for eventually forming solder joints with the said chip, the quantities of solder for deposit on the said minor bond areas being proportioned to ensure that the eventual bond formed about these minor areas will have generally concave side walls.

5. A method of making a flip chip bonded hybrid integrated circuit device substantially as hereinbefore described with reference to the accompaying drawings.

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